

Q. Explain the uses of Quantum dot in solar cell and LED Device.

Quantum Dots in solar cell:-

- (i) Tunable Bandgap:- The size of quantum dots determines their bandgap, allowing them to absorb a broader range of the solar spectrum.
- (ii) Multiple Exciton Generation:- A single high energy photon can generate multiple electron-hole pairs, improving efficiency.
- (iii) Low-cost Fabrication:- Quantum dot solar cells can be made by using low-cost solution-based techniques.
- (iv) Improved stability:- Quantum dot solar cells are more stable than organic solar cells due to the inorganic nature of quantum dots.

Quantum Dots in LED Devices:-

1. Color Tunability:- The size of quantum dots determines the color of light they emit, enabling a wide range of colors in LED displays.
2. High Efficiency:- Quantum dot LEDs can achieve higher efficiency than traditional LEDs due to the quantum confinement effect.

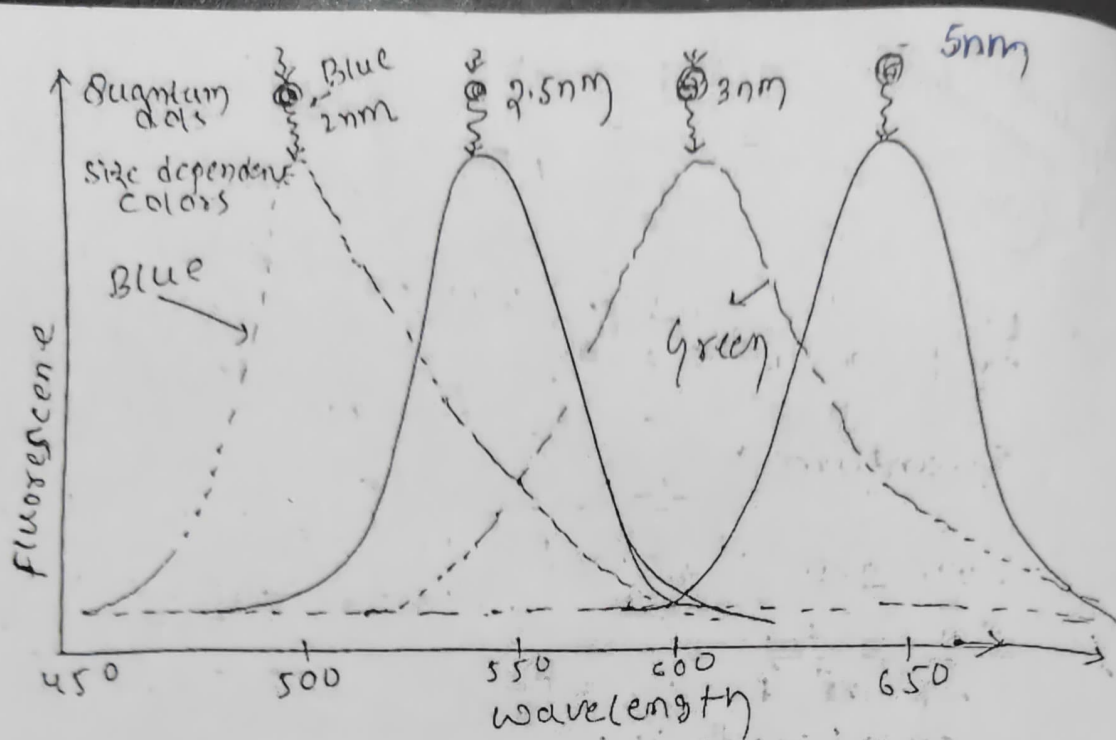


Fig. 1: Size Dependent Fluorescence in QD LED.

✓ Write down the applications of Nanowire,

→ • Electronics:-

Nanowires can be used to create high performance transistors, logic gates, and memory devices for integrated circuits and nanoelectronics.

• Energy:-

Nanowires are used in solar cells, batteries, and thermoelectric devices to improve efficiency and performance.

• Sensing:-

The high surface area of nanowires makes them excellent sensors for detecting chemical, biological and environmental substances.

• Optics:-

Nanowires can act as waveguides and lasers for optical communication and information processing.

- Biomedical:
nanowires can be used for targeted drug delivery, tissue engineering, and biosensing applications within the human body.

Q. Explain the uses of nanowires in solar cells
or
Explain how the efficiency of solar cells can be improved by using of nanowires.

→ (i) More light absorption:-

Nanowires have a high surface area to volume ratio, allowing them to absorb more light compared to bulk materials, leading to higher energy conversion efficiency.

(ii) Less material needed:-

By using nanowires, such as GaAs (GAs), the amount of material required for solar cells can be greatly reduced while maintaining high efficiency, improving cost-effectiveness.

(iii) Better charge collection:-

The small diameter of nanowires facilitates efficient collection of charge carriers (electron and hole) generated by absorbed light, minimizing recombination losses and enhancing overall efficiency.

(iv) Customizable light absorption:-

The bandgap of nanowires can be tuned by controlling their size and composition, enabling the absorption of a wider range of the solar spectrum and improving efficiency.

(v) Flexible and lightweight:-

Nanowire-based solar cells can be made flexible and lightweight, opening up new applications such as portable electronics and building-integrated photovoltaics.

Q. Write down the Advantage and drawback of using nanowires in solar cell.

— Advantages:-

- (i) Reduced reflection and improved light trapping allowing dense absorption across the entire solar spectrum.
- (ii) Facile strain relaxation and increased defect tolerance, enabling higher efficiency.
- (iii) Improved band gap tuning for better light absorption.
- (iv) Radial geometry that enhances band gap tuning strain relaxation, and defect tolerance.

Drawbacks:-

- (i) High roughness causes adhesion and corrosion issues.
- (ii) Degradation under UV and visible light exposure.
- (iii) poor electrical contact at wire-wire junctions.
- (iv) Limited electromagnetic absorption range of silicon nanowires.

Q. Explain the uses of nanowires in LED devices.

or
Write down the Advantages of nanowires in LED devices.

- (i) Nanowires can directly emit light when an electric current is applied; (ii) utilize unique physical mechanisms at the nanoscale for efficient light emission.

- (ii) Combining nanowires and nanowalls creates p-n junctions that can emit light.
- (iii) Nanowires enable LEDs to be integrated into flexible and transparent electronics. Small size and high aspect ratio of nanowires allow non-planar device geometries.
- (iv) unique properties of nanowire material like III-nitrides boost LED efficiency.
- (v) nanowires can be tuned to emit different colors of light.

Q. What is single electron transistor (SET) and Coulomb blockade.

→ Coulomb blockade:-

The Coulomb blockade is a phenomenon in which the flow of electrons is restricted in small electronic devices due to strong electrostatic repulsion between the electrons.

This creates an energy barrier that blocks electron flow until a threshold voltage is reached, resulting in a "staircase" current-voltage relationship instead of Ohm's Law.

Single electron transistor (SET):-

A single electron transistor (SET) is an electronic device that utilizes the advantages of Coulomb blockade phenomenon in controlling the transfer of individual electrons to the quantum dot.

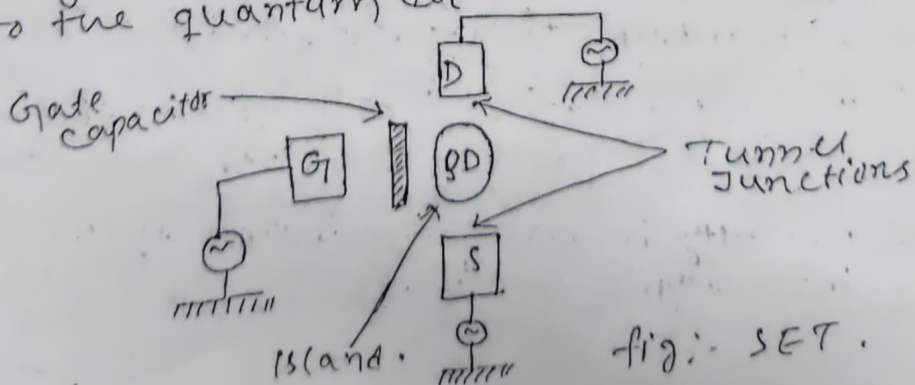


fig:- SET.

key points about SETs.

- SETs have a small island between two barriers that electrons must pass through.
- The Coulomb blockade creates an energy barrier that blocks electrons until the gate voltage overcomes it.
- This allows SETs to precisely control the flow of single electrons.
- SETs are very sensitive and use little power, but need cold temp. to work well.
- They have special uses like ultra-precise measurements but are not as versatile as regular transistors.

Write down the Advantages, Drawbacks and Applications of SET.

→ Advantages:-

- (i) Extremely low power consumption by controlling individual electrons.
- (ii) High sensitivity for detecting and manipulating single electrons.
- (iii) Scalability at atomic scale, enabling high integration density.
- (iv) Fast information transfer due to rapid electrostatic interactions.

Drawbacks:-

- (i) Integration challenges, difficult to fabricate and integrate into circuits.
- (ii) Temp dependence, typically requiring cryogenic temp. to operate.
- (iii) Difficulty in connecting individual structures into logic circuits.

Applications:-

- (i) ultrasensitive electrometers for detecting tiny charge changes.
- (ii) single-electron spectroscopy to study quantum dot energy levels.
- (iii) precise DC current standards based on quantized current flow.
- (iv) infrared and terahertz radiation detection via single-electron sensitivity.
- (v) voltage/charge state logic gates and circuits enabling ultra-low power digital electronics.

Q. Write a short note on CNT based Transistor.

→ Introduction:-

Carbon nanotubes (CNTs) have emerged as a promising alternative to traditional silicon-based transistors due to their exceptional electrical, thermal and mechanical properties. CNT transistors utilize a single carbon nanotube or an array of carbon nanotubes as the channel material, in contrast to the bulk silicon used in conventional metal-oxide-semiconductor field effect transistors (MOSFETs).

Featured properties of CNTs:-

- (i) CNTs can act as either metallic or semiconducting materials, enabling high-performance electronic devices.
- (ii) CNTs can efficiently dissipate heat, making them suitable for high-power applications.
- (iii) CNTs are one of the strongest materials known, allowing for robust and flexible electronic components.

Working principle:-

The structure and operation of CNT transistor are similar to conventional MOSFETs, with the main difference being the channel material. In a CNT transistor, the current flows through the carbon nanotube channel, which is controlled by the gate electrodes. This allows for faster switching speeds and lower power consumption compared to silicon-based transistors.

Q. Write down the Advantages and Drawbacks of CNTFET.

→ Advantages:-

- (i) Better control over formation of channel in the device.
- (ii) High electron mobility hence better conduction.
- (iii) Lower threshold voltage.
- (iv) High current density.

Drawbacks:-

- (i) Performance depends on the ambient temperature.
- (ii) CNTFET is not much more reliable. Its reliability is affected due to the avalanche breakdown in semiconductor carbon nanotubes and due to Joule breakdown in metallic carbon nanotubes.
- (iii) CNTFETs have shorter lifetime as carbon nanotubes degrade in a few days when exposed to oxygen.

Q. What is difference between CNTFET and conventional FET.

- CNTFET uses a carbon nanotubes as the channel material, while conventional FET uses bulk silicon.
- CNTFET have higher on current, transconductance and carrier velocity compared to MOSFET.
- CNTFET exhibit better control over channel formation, threshold voltage and subthreshold slope than MOSFETs.
- CNTFET can achieve higher current density and linearity due to their unique 1D structure and ballistic transport.

Q. Write a short note on the following -

- (i) Quantum Dot Heterostructure Lasers
- (ii) Optical switching.
- (iii) Optical storage.

→ (i) Quantum Dot Heterostructure Laser :-

Quantum dot (QD) heterostructures are nano-scale coherent insertions of narrow-gap material in a single crystalline matrix. The tight confinement of charge carriers in QDs gives them an electronic structure similar to atoms, allowing laser fabricated with QD active media to exhibit performance closer to gas lasers.

Key characteristics of QD heterostructure lasers-

- The QD active region can be engineered to operate at different wavelength by varying dot size and composition.

- Improved modulation bandwidth, ^{lasing} threshold, relative intensity noise, linewidth enhancement factor and temp insensitivity compared to traditional semiconductor lasers.
- Stacking QD layers can narrow the linewidth by forming more uniform, equal sized QDs.

(ii) optical switching :-

optical switching is a critical technology for enabling high-capacity, low latency and energy efficient optical communications network. It involves using optical switches to direct light signals between optical fibres allowing for high-speed data transmission over long distances with minimal signal degradation.

key features of optical switching :-

- Faster switching times compared to electrical switching, enabling higher-speed data transmission.
- operates in the photonic domain, avoiding power hungry electrical-to-optical and optical-to-electrical conversions.
- can handle massive bandwidth requirements by switching data directly in the optical domain.
- offers wavelength selectivity, enabling wavelength division multiplexed (WDM) optical networks.

(iii) optical storage:-

optical storage refers to a class of data storage systems that use light to read or write data to an underlying optical media.

The most common examples ^{are} optical discs like the compact disc (CD), digital versatile disc (DVD) and Blu-ray disc (BD).

Data is recorded by making marks in a pattern that can be read back with the ^{help} of a laser beam ^{precisely} focused on a spinning optical disc.

Key features of optical storage:-

- ✓ High storage capacity, ranging from 700 MB for ^{compact} CDs to 128 GB for quad-layer BDs.
- ✓ Durability and resistance to environmental factors due to physical separation of data layers.
- ✓ Slower access time compared to magnetic and solid-state storage.
- Reliance on mechanical components and compatibility issues.

Q. Write the Advantages and Drawbacks of optical storage devices.

→ Advantages:-

- (i) High storage capacity.
- (ii) Durability and environmental resistance.
- (iii) Low cost per bit of storage.
- (iv) portability and ease of use.
- (v) Long media life.

Drawbacks:-

- (i) slower data access and transfer speed
- (ii) Reliance on mechanical components.
- (iii) Limited storage capacity
- (iv) Bulkier and less portable.
- (v) Susceptibility to data corruption.

Q. What is magnetic storage device? How many types are there. Write their uses.

→ Magnetic storage devices are a types of non-volatile storage that uses magnetic field to record and retrieve digital data.

Types of magnetic storage devices:-

- (i) Hard Disk Drives (HDDs)
- (ii) Magnetic Tapes
- (iii) Floppy Disks
- (iv) Magnetic stripe cards
- (v) Magnetic Bubble Memory.

uses:-

(i) Hard Disk Drives (HDDs):-

primary storage in computers and servers for operating systems, applications and user data.

(ii) Magnetic Tapes:-

Backup, archiving and long-term data storage in data centers and organizations.

(iii) Floppy Disks:-

Portable storage for transferring files between computers.

(iv) Magnetic Stripe Cards:-
storing encoded user information for credit/debit cards and ID cards.

(v) Magnetic Bubble Memory:-
specialized applications like military and aerospace systems requiring radiation and shock resistance.

Q. What is microelectro mechanical systems (MEMS)? Write their Advantage and application.

→ Microelectro mechanical systems (MEMS):-

microelectro mechanical systems are microscopic devices that integrate electrical and mechanical components on a common silicon substrate using microfabrication technology. These miniaturized systems combine sensors, actuators and control logic to perform specific func.

Advantages:-

- (i) Highly scalable manufacturing resulting in low unit costs when mass-produced.
- (ii) Extremely high sensitivity in sensors.
- (iii) Ability to attain very high frequencies in switches and actuators.
- (iv) very low power consumption.

Applications:-

- (i) Inertial sensors (accelerometer and gyroscopes) in smartphones and wearables.

- (ii) pressure sensors in automotive and ~~medical~~ medical applications.
- (iii) Micromirror arrays in digital light processing (DLP) projectors.
- (iv) Radio frequency (RF) switches and tunable capacitors in wireless communication.

Q. What is Nanoelectromechanical systems (NEMS)? Write their Advantages and Applications.

→ Nanoelectromechanical systems (NEMS) are devices that integrate electrical and mechanical functionality on the nanoscale, typically ranging from hundreds to a few nanometers in critical dimensions.

NEMS represent the next logical miniaturization step from MEMS.

They integrate transistor like nanoelectronics with mechanical actuators, pumps or motors to form physical, biological and chemical sensors.

Advantages:-

- (i) Extremely small size, allowing for high-density integration and low power consumption.
- (ii) High mechanical resonance frequencies in the microwave range (up to 100 Hz).
- (iii) Potentially large quantum mechanical effects like zero point motion.
- (iv) High surface-to-volume ratio enabling sensitive surface-based sensing mechanism.

Applications:-

- (i) Highly sensitive accelerometers and chemical sensors.
- (ii) High-frequency oscillators and switches for wireless communications.
- (iii) Nanomotors and actuators for micro-robotics and drug delivery.
- (iv) Scanning probe microscopy for high resolution imaging and manipulation.

Q. Describe how the nanomaterials are used in photonic device like LED and solar cells

→ Here are the some key points on how nanomaterials are used in photonic devices like LEDs and solar cells.

LEDs:-

- (i) Quantum dots can produce highly specific light emissions.
- (ii) Quantum dots enable accurate colour rendering and power efficiency.
- (iii) Quantum dots of varying sizes can be stacked to emit specific wavelengths.
- (iv) Nanoparticles and thin films can modify the electronic and optical properties of LED materials.

Solar cells:-

- (i) Quantum dots of varying sizes can be stacked to absorb a broader range of the solar spectrum.
- (ii) Nanoparticles

- (ii) nanoparticles and thin films can modify the electronic and optical properties of photovoltaic materials.
- (iii) nanoparticles and thin films improve light absorption in solar cells.
- (iv) nanoparticles and thin films improve charge transport in solar cells.

Q. Explain how the concept of optical switching is used in optical data storage device.

→ optical switching plays a crucial role in optical data storage devices presented by

(i) Rapid on/off switching:-

It allows the laser to be switched on and off rapidly to create the microscopic pits that represent the binary data on the recording layer within the disc.

(ii) Precise focusing:-

Optical switching enables the laser to be precisely focused on the recording layer within the disc, which is necessary for writing and reading data at high densities.

(iii) High-speed data transfer:-

By precisely controlling the laser beam, optical switching allows for fast data transfer rates and high storage densities in optical discs.

(iv) Efficient data retrieval:-

Optical switching eliminates the need for electrical-to-optical conversion

reducing latency and improving the efficiency of data retrieval from optical discs.

What do you mean by single-electron tunnel phenomenon? Write the differences between single-electron transistor and normal transistor.

Single-electron tunneling is a quantum phenomenon where an electron tunnels through an insulating barrier between two conductors, with only one electron tunneling at a time. This quantized transfer is influenced by the charging energy and enables sensitive electronic devices like single-electron transistor.

Difference between single-electron transistor and a normal transistor -

<u>Single electron transistor</u>	<u>Normal Transistor</u>
operates on the principle of single electron tunneling.	(i) operates on the principle of the <u>flow</u> of many electrons.
Allows precise control of the flow of individual electrons.	(ii) Controls the current and voltage in a electronic circuit
Enables extremely small device sizes, potentially enabling higher density	(iii) Has larger device sizes with more established manufacturing processes
Offers the potential for lower power consumption compared to traditional transistors.	(iv) Has a wider range of applications in digital and analog circuits.

Q. Write down the uses of nanostructured thin film.

→ (i) Solar cells :-

Nanostructured thin films can ~~enchan~~ enhance light absorption and trapping in thin-film solar cells, improving the efficiency.

(ii) Sensors :-

Nanostructured thin films of materials WO_3 can be used as highly sensitive sensors, detecting substances like H_2 and CO_2 .

(iii) Energy storage :-

Thin films batteries with nanostructured electrodes can provide high energy and power density for specialized applications.

Q. (i) What is carbon nanotubes? Discuss about different types of carbon nanotubes?

(ii) Write and explain the properties of carbon nanotubes.

⇒ (i) carbon nanotubes are cylindrical allotropes of carbon with a nanometer-scale diameter. They exhibit extraordinary strength, unique electrical properties, and thermal conductivity, making them suitable for various applications.

Types of carbon nanotubes:-

(a) Single-walled carbon nanotubes (SWCNTs):-

- consist of a single graphene sheet rolled into a cylinder.
- Diameter range from 1-5 nm and length over 1 mm
- Exhibit high electrical conductivity and tensile strength.

(b) Multi-walled carbon nanotubes (MWCNTs):-

- Comprise multiple concentric graphene cylinders.
- Diameter range from 2-100 nm and length over 1 mm
- Have lower electrical conductivity and tensile strength compared to SWCNTs

(c) Double-walled carbon nanotubes (DWCNTs) and Few-walled carbon nanotubes (FWCNTs):-

- Intermediate properties between SWCNTs and MWCNTs.
- Offer a balance between cost-effectiveness and performance.
- Suitable for applications requiring moderate electrical and mechanical properties.

(ii) Properties of carbon nanotubes:-

(a) Electrical properties:-

High electrical conductivity due to delocalized electrons and they can exhibit metallic or semiconducting behavior based on chirality and diameter.

(b) Mechanical properties:-

Extremely strong and stiff, with a tensile strength 100 times greater than steel and young's modulus around 1 TPa, making them 10 times stronger than steel.

(c) Thermal properties:-

- High thermal conductivity along the tube axis
- Low coefficient of thermal expansion.
- High thermal stability with a melting point around 3550°C .

(d) Other properties:-

- High surface area to volume ratio
- Chemically stable and resistant to corrosion
- Lightweight with a density one-fourth that of steel.

Q. What do you mean by magnetoresistance?
Describe different types of magnetoresistance.

→ Magnetoresistance is the change in material's electrical resistance when exposed to a magnetic field. This effect has important applications in magnetic sensing, memory and data storage technologies.

Types of magnetoresistance:-

(i) Anisotropic (AMR):-

Resistance changes with angle between current and magnetization in ferromagnets.

(ii) Giant (GMR):-

Large resistance change in thin film structures with alternating ferromagnetic and non-magnetic layers, based on relative magnetic alignment.

(iii) Tunnel (TMR):-

Resistance changes due to spin-dependent tunneling in magnetic junctions.

(iv) Colossal (CMR):-

Extremely large resistance change in doped manganites.

(v) Extraordinary (EMR):-

Resistance change in semiconductor-metal composites without magnetic materials. ✓

Q. What do you mean by nanostructured material?
→ Nanostructured materials are materials with structured in the nanometer range (1-100 nm) that exhibit unique properties due to their small size and high surface area-to-volume ratio.

ex:- nanostructured titanium dioxide has enhanced photocatalytic and self-cleaning abilities compared to bulk titanium dioxide.

Q. Write the importance of defects in nano-
-materials.

→ Defects in nanomaterials significantly alter their surface reactivity, catalytic performance, and electronic structure, making them crucial for tuning optical, electronic, magnetic and catalytic properties.

Q. What are nanowires? What unique properties do they possess at nanoscale?

→ Nanowires are 1-D nanostructures with diameter ranging from 10 to 100 nm that exhibit unique electrical, optical, thermal and surface properties due to quantum confinement effects at the nanoscale.

Q. What properties of nanoparticles make it useful in the development of high performance electronic display?

→ Nanoparticles have unique optical and electronic properties, high surface area, and ability to create novel display architectures, making them useful for developing advanced, high performance electronic displays like quantum dot LED and field emission displays.

Q. Describe the working theory of solar cells.

→ Working Theory :-

- photons in sunlight strike the semiconductor material in a solar cell.
- photons with energy greater than the semiconductor's band gap excite electrons from the valence band to the conduction band.

- These electrons-hole pairs that are separated by the built-in electric field of the p-n junction.
- The electrons are swept to the n-type side and the holes to the p-type side, generating a voltage.
- Ohmic contacts allow the electrons and holes to be collected and flow through an external circuit, producing electric current.

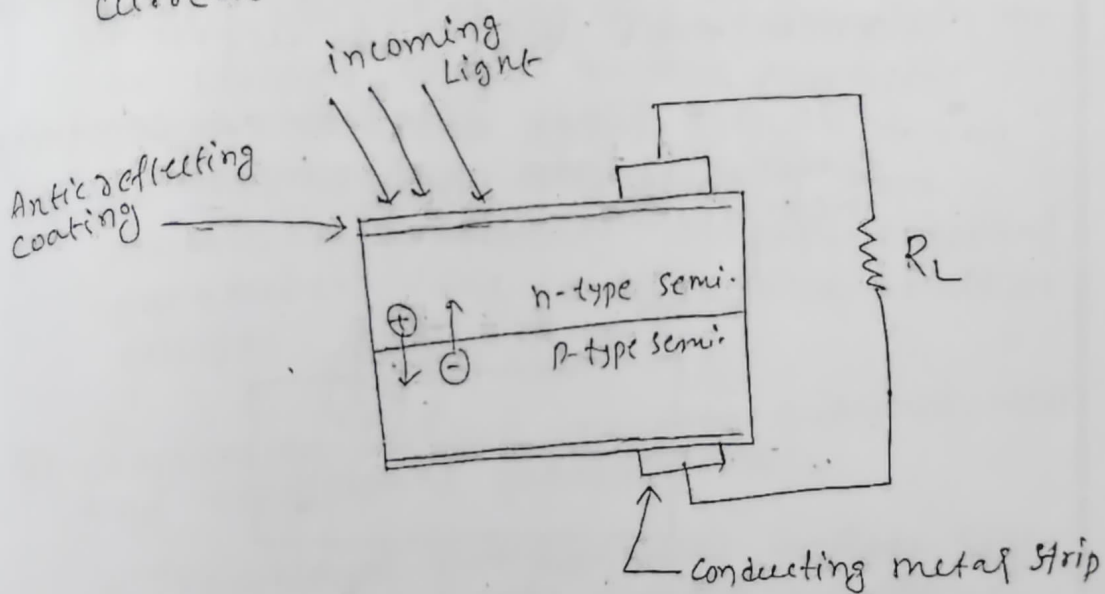


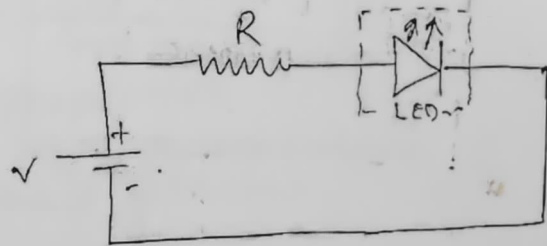
fig:- Labelled diagram of Solar cells.

- Q. (i) Explain the working theory of LEDs. (ii) Write two practical applications of LED.

→ (i) Working Theory:-

- LEDs are semiconductor devices that emit light when an electric current flows through them.
- They contain a p-n junction - a boundary between p-type and n-type semiconductor materials.

- When forward biased, electrons from the n-type material recombine with holes in the p-type material. This recombination releases energy in the form of photons (energy).
- The wavelength (colour) of the emitted light depends on the semiconductor material and its bandgap energy.
- Certain materials produce red, green, blue or other colours of visible light, while others emit infrared or ultraviolet.
- LEDs are highly efficient at converting electricity into light compared to incandescent bulbs.



LED circuit.

(ii) Applications:-

- Efficient lighting in homes, vehicles and outdoor displays
- High-quality displays in TVs, phones and digital signage.
- Indicator lights on electronic devices and equipment.

- Q. (i) What is magnetic quantum well?
- (ii) How does it differ from a traditional quantum well structure?
- (iii) What are the unique properties and behaviors exhibited by electrons in a magnetic quantum well due to the presence of magnetic field?

→ (i) A magnetic quantum well is a quantum well structure that incorporates magnetic materials, enabling the electron spin to be strongly coupled to the magnetic properties. This allows active control of the electron spin splitting and precession frequency through external parameters like electric field or laser energy.

(ii) Comparison between magnetic quantum well and traditional quantum well -

- Traditional quantum wells confine electronic properties, magnetic quantum well confine magnetic properties.
- Traditional wells use semiconductor materials, magnetic wells use magnetic nanoparticles.
- Traditional wells control charge carrier motion, magnetic wells control magnetic moment orientation.
- Traditional wells exhibit quantum size effect on electronic states, magnetic wells exhibit quantum effects on magnetic states.

(iii) Here are the key points about the unique properties and behavior of electron in a magnetic quantum well is given —

- Quantized electronic states due to magnetic multilayer structure.
- oscillations in magnetic coupling and magnetoresistance.
- Enhanced spin-dependent reflectivity for giant magnetoresistance.
- spin doping to manipulate spin currents.
- production and detection of spin-polarized electrons.
- precise control of electronic and magnetic properties at the nanoscale.

8. Do a comparative analysis of quantum dots, nanowires and thin films with respect to the application in photonic devices.

→ Quantum Dots:-

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- (i) semiconductor nanocrystals with tunable optical properties based on size.
- (ii) used in LEDs, solar cells, and photodetectors due to high quantum efficiency and ability to absorb/emit specific wavelengths.
- (iii) offer high brightness, color purity and energy efficiency in displays and lighting applications.

Nanowires :-

- (i) 1D semiconductor structures that can act as waveguides.
- (ii) Enable efficient light confinement and transport.
- (iii) promising for lasers, photodetectors and optical interconnects due to their ability to guide and manipulate light.

Thin films :-

- (i) nanometer-scale layers of materials deposited on a substrate.
- (ii) can control light propagation and interaction.
- (iii) used to fabricate optical filters, waveguides and modulators.
- (iv) offers precise control over light properties like polarization, intensity and phase.

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